

Intermediate mass dilepton production in heavy-ion collisions at SPS energies*

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Through the analysis of HELIOS-3 data on dilepton spectra, we demonstrate the importance of secondary processes for the dilepton production in heavy-ion collisions in the intermediate mass region. We find that, while the dilepton spectra in proton-induced reactions can be nicely explained by the decay of primary vector mesons, charmed hadrons, and initial Drell-Yan processes, the strong enhancement seen in the heavy-ion data comes mainly from the secondary meson-meson interactions which are unique to heavy-ion collisions.

The experimental measurement and theoretical investigation of dilepton production in heavy-ion collisions constitutes one of the most active and exciting fields in physics. Because of their relatively weak final-state interactions with the hadronic environment, dileptons are considered ideal probes of the early stage of heavy-ion collisions, where quark-gluon-plasma (QGP) formation and chiral symmetry restoration are expected.

Recent observation of the enhancement of low-mass dileptons in central heavy-ion collisions by the CERES [1,2] and the HELIOS-3 [3] collaborations has generated a great deal of theoretical activities. The results from many groups with standard scenarios (i.e., using vacuum meson properties) are in remarkable agreement with each other, but in significant disagreement with the data: the experimental spectra in the mass region from 0.3-0.6 GeV are substantially underestimated [2]. This has led to the suggestion of various medium effects that might be responsible for the observed enhancement [4,5].

Another piece of interesting experimental data that has not received much theoretical attention is the dilepton spectra in the intermediate-mass region between 1 and 2.5 GeV. Both the HELIOS-3 and NA38/NA50 collaborations have observed a significant enhancement of dilepton yield in this mass region in central S+W and S+U collisions as compared to that in the proton-induced reactions [3,6]. The intermediate-mass dilepton spectra are particularly useful for the search of the QGP. It was originally suggested that in this mass region, the electromagnetic radiation from the QGP phase might shine over that from the hadronic phase. However, to extract from the measured dilepton spectra any information about the phase transition and the properties of the QGP, it is essential that the

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contributions from the hadronic phase be precisely understood and carefully subtracted.

In this contribution we report our recent study of dimuon spectra in central S+W collisions [8]. Previous thermal rate calculations show that in the mass and temperature region relevant for this study, the following hadronic processes are important: $\pi\pi \rightarrow l\bar{l}$, $\pi\rho \rightarrow l\bar{l}$, $\pi\omega \rightarrow l\bar{l}$, $\pi a_1 \rightarrow l\bar{l}$, $K\bar{K} \rightarrow l\bar{l}$, and $K\bar{K}^* + c.c. \rightarrow l\bar{l}$ [9–12]. The cross sections for the annihilation of pseudoscalar mesons are well known [13]. The pion electromagnetic form factor is dominated by the $\rho(770)$ meson, while that of the kaon is dominated by the $\phi(1020)$ meson. At large invariant masses, higher ρ -like resonances such as $\rho(1450)$ were found to be important. The cross sections for $\pi\rho \rightarrow l\bar{l}$ and $\bar{K}K^* + c.c. \rightarrow l\bar{l}$ have been studied in Ref. [11]. High isoscalar vector mesons such as $\omega(1420)$ and $\phi(1680)$ play important roles in these processes. The cross section for $\pi\omega \rightarrow l\bar{l}$ has the same form as that for $\pi\rho \rightarrow l\bar{l}$, but with a different form factor.

The cross section for $\pi a_1 \rightarrow l\bar{l}$ needs some special attention, since this process has been found to be particularly important in the intermediate-mass region. In Ref. [14], a comparative study was carried out for several existing models for the $\pi\rho a_1$ dynamics. By using the experimentally-constrained spectral function [15], it was found that the effective chiral Lagrangian of Ref. [16] provides the best off-shell, as well as on-shell, properties of the $\pi\rho a_1$ dynamics. The extraction of the form factor for $\pi a_1 \rightarrow l\bar{l}$ from $e^+e^- \rightarrow \pi^+\pi^-\pi^+\pi^-$ still involves uncertainties in regarding whether the $\rho(1700)$ resonance couples to πa_1 or not. We will thus consider two scenarios for the $\pi a_1 \rightarrow l\bar{l}$ form factor, one with and one without the $\rho(1700)$ contribution.

For dilepton spectra with mass above 1 GeV, the contributions from charm meson decay and the initial Drell-Yan processes begin to play a role. These hard processes, however, scale almost linearly with the participant nucleon number, and can thus be extrapolated from the proton-proton and proton-nucleus collisions. The results corresponding to the HELIOS-3 acceptance are shown in the left window of Fig. 1, which are taken from Ref. [2]. These, together with the dileptons from the decays of primary vector mesons, are collectively labeled ‘background’. It is seen that these background sources describe very well the dimuon spectra in the p+W reactions. However, as can be from the figure, the sum of these background sources grossly underestimates the dimuon yield in central S+W collisions, which indicates additional sources to dilepton production in heavy-ion collisions. This can come from the thermalized QGP and/or hadronic phases. So the immediate next step is to check whether the contribution from the secondary hadronic processes can explain this enhancement, which is the chief purpose of this work.

The contributions from the secondary processes outlined above are shown in the middle panel of Fig. 1. These are obtained in the relativistic transport model of Refs. [4], including the HELIOS-3 acceptances, mass resolution, and normalization [3]. It is seen that the πa_1 process is by far the most important source for dimuon yields in this mass region, as was found in many thermal rate calculations. The $\pi\omega$ process also play some role in the entire intermediate mass region, while the contributions from $\pi\pi$, $\pi\rho$ and $K\bar{K}$ are important around 1 GeV invariant mass. In the right panel of Fig. 1, we compare the sum of the secondary and background contributions with the HELIOS-3 data for central S+W collisions. It is seen that the data can now be nicely explained. Thus we showed for the first time the importance of the secondary processes for the intermediate-mass dilepton spectra in heavy-ion collisions. Although the current data do not show any necessity to

invoke the QGP formation in S-induced reactions, consistent with conclusions from J/Ψ physics, the observation that the secondary processes do play an important role in the intermediate-mass dilepton spectra is interesting and important.

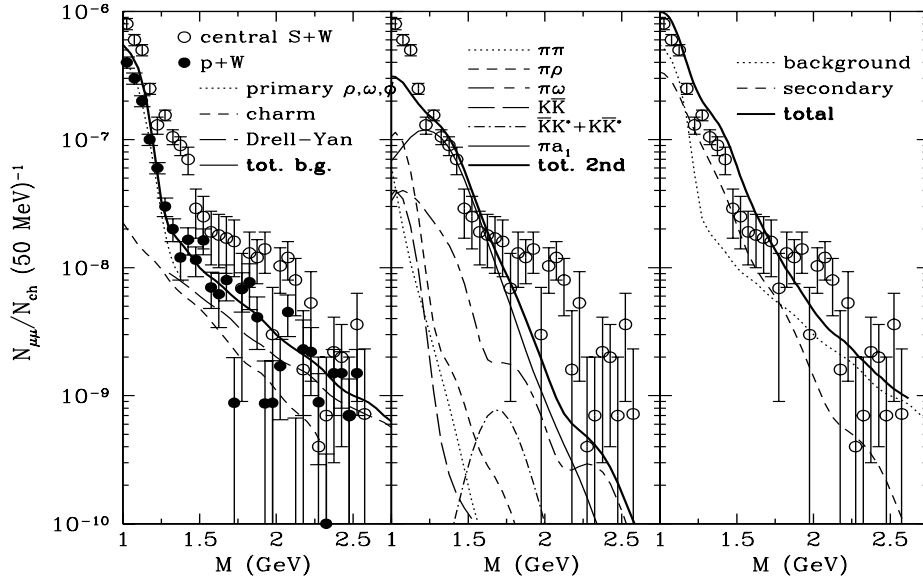


Figure 1. Left panel: comparison of backgrounds with experimental data in p+W and S+W collisions. Middle panel: contributions of various secondary processes to the dimuon spectra in central S+W collisions. Right panel: comparison of the sum of the background and secondary contributions with the experimental data in central S+W collisions.

In the previous calculation we included $\rho(1700)$ in the πa_1 form factor. we also did a calculation in which the πa_1 form factor contains only the normal $\rho(770)$. From the formal point of view there is little evidence that $\rho(1700)$ couples to πa_1 . The results are shown in the left panel of Fig. 2 by the dotted curve. Apparently, with a form factor that excludes the $\rho(1700)$ resonance, the contribution from the πa_1 process is reduced. The agreement with the HELIOS-3 data in this case is slightly better. Another issue we address is the effects of dropping meson masses on the dimuon spectra from the threshold to about 2.5 GeV. Below 1.1 GeV and especially from 0.4 to 0.6 GeV, the agreement with the experimental data is much better when the dropping mass scenario is introduced. At higher masses, the dropping mass scenarios somewhat underestimates the experimental data. In this mass region, however, there might be additional contributions from, e.g., secondary Drell-Yan processes [17] that were not included in this study.

In summary, we have analysed the recent HELIOS-3 data on intermediate-mass dilepton production in heavy-ion collisions at the CERN SPS energies using the relativistic transport model. We have shown the importance of secondary processes for the dilepton production in heavy-ion collisions in this mass region. we found that $\pi a_1 \rightarrow l\bar{l}$ to be the most important, as was found in many thermal rate calculations.

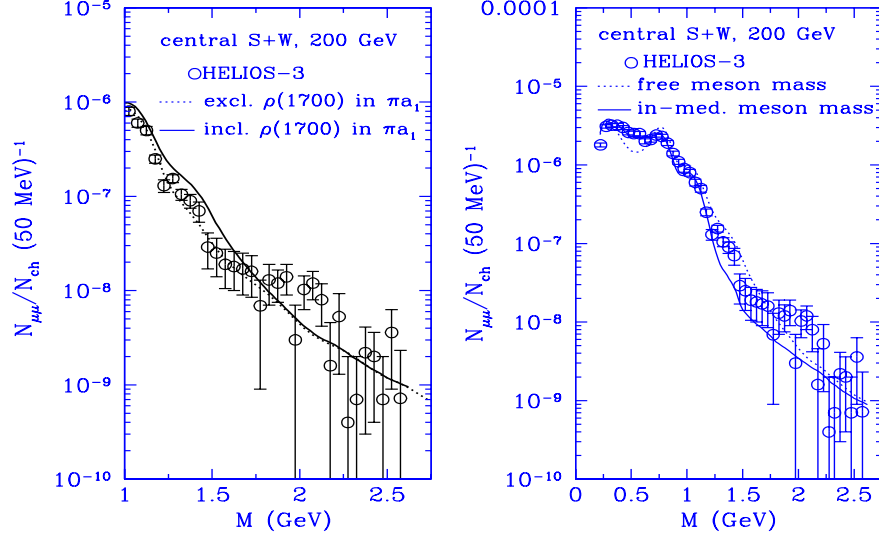


Figure 2. Left panel: comparison of dimuon spectra obtained with and without the $\rho(1700)$ in the πa_1 form factor. Right panel: Comparison of dimuon spectra with im-medium and vacuum meson masses.

The current investigation can be extended to higher incident energies, such as those of RHIC collider, by combining the cross sections (or thermal rates) obtained in this study with, e.g., hydrodynamical models for the evolution of heavy-ion collisions at the RHIC energies. This kind study will be very useful for the determination of hadronic background in the dilepton spectra, and for the clear identification of the dilepton yield from the QGP.

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